



## Project Summary

# Characterization of PM-10 Emissions from Antiskid Materials Applied to Ice- and Snow-Covered Roadways—Phase II

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Several areas of the country in violation of the National Ambient Air Quality Standard for PM-10 have conducted studies identifying the resuspension of antiskid materials from urban paved roads as an important emission source. In this study, a field sampling program was conducted on 47th Street in Kansas City, MO, during February and March 1993 to quantify the PM-10 emissions associated with the use of rock salt (NaCl) for ice and snow control. A baseline test was conducted in September 1993. The emissions were determined using exposure profiling. The measured emission factors spanned the following ranges, in grams per vehicle kilometers traveled (g/VKT):

- Total PM-10: 0.2 to 1.7 (winter tests); 3.9 to 4.9 (September test)
- PM-10 lead: 7.5 (10)<sup>-5</sup> to 4.5 (10)<sup>-4</sup> (winter tests)
- PM-10 NaCl: 0.014 to 0.039 (winter tests)

The winter emission factors for total PM-10 determined in this study were about an order of magnitude lower than those measured in a 1992 Duluth study which utilized a 90% sand/10% salt antiskid material. The studies concluded that the sand from the antiskid material mixture that remained after the road had dried, constituted most of the silt loading and, therefore, the PM-10 emission impact. The rock salt, removed from the road mostly in the melting slush, contributed only a few percent to the residual silt loading.

*This Project Summary was developed by the National Risk Management Re-*

*search Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

Several areas of the country that are in violation of the National Ambient Air Quality Standard for PM-10 (airborne particles less than or equal to 10  $\mu\text{m}$  in diameter) have conducted studies to determine the sources of these emissions. One source of PM-10 emissions identified in a number of these studies is the resuspension of antiskid material applied to paved roadways. Antiskid materials may consist of (a) abrasives, such as sand, stone, or cinders, applied to the road surface to improve traction or (b) "deicers," which restore pavement traction by preventing the formation of ice films, weakening the ice/pavement bond, and/or melting ice and snow.

The application of antiskid materials, especially low durability abrasives, can create a temporary, but substantial, increase in the amount of fine particles on the road surface over that which is normally present. Prior research has established a direct relationship between the loading of silt-size fines (particles <75 $\mu\text{m}$  in physical diameter) and the PM-10 emissions generated by vehicular traffic. The empirical relationship between silt loading and PM-10 emissions is reflected in the EPA-recommended PM-10 emission factors for paved urban roads. This relationship was developed from a data base encompassing the

results of tests conducted under dry conditions at eight sites, ranging from a free-way to a rural town road.

More recently, a revised emission factor model for predicting the PM-10 emissions from paved roads has been incorporated into the 5th edition of EPA report AP-42. This model is expressed as

$$E = 4.6 \left( \frac{sL}{2} \right)^{0.65} \left( \frac{W}{3} \right)^{1.5} \quad (1)$$

where: E = PM-10 emission factor (grams per vehicle kilometers traveled—g/VKT)  
 s = surface silt content (fraction of particles < 75µm in physical diameter)  
 L = total road surface dust loading (g/m<sup>2</sup>)  
 W = average weight (tons) of the vehicles traveling on the road

The total loading (excluding litter) shown in Eq. (1) is measured by sweeping and vacuuming lateral strips of a known area from each active travel lane. The silt fraction is determined by measuring the proportion of loose dry road dust that passes a 200-mesh screen, using a modified version of ASTM C 136. Silt loading is the product of total loading and silt content. Average vehicle weight is determined from observations of the mix of traffic on the road.

To evaluate the applicability of available emission factors to roads treated with antiskid materials, PM-10 emission testing of a six-lane arterial located in Kansas City, MO, was conducted. The first testing phase in February and March 1993 was devoted to the characterization of emissions from the road after the application of a common deicer (rock salt) for ice and snow control. The second testing phase in September 1993 determined the PM-10 emissions from the same road without the influence of the deicing chemical. The results of these tests are summarized below.

## Site Description

The test site was 47th Street between Rockhill Road and Oak Street in Kansas City, MO. This road is a six-lane arterial maintained as part of Kansas City's boulevard system. This road is used by commuter traffic to and from a major shopping and business area of the city at an approximate volume of 30,000 vehicles/day. Data collected during field sampling showed that essentially all of the traffic

was two-axle, light-duty vehicles traveling at an average speed of 46 km/h (29 mph). Surface loadings determined both visually and by sampling were generally very low, with nominal silt loadings of about 0.2 g/m<sup>2</sup>.

The site was suitable for a number of reasons, including its east-west orientation with respect to prevailing north-south ambient winds, good cooperation by the local transportation agency (City of Kansas City, Parks and Recreation Department), and the relatively high traffic volume during daylight hours. In addition, the wide median allowed for testing of half the total road width (one traffic direction), thereby helping to limit the vertical extent of the plume at the point of downwind sampling.

## Overall Study Design

The source-directed field sampling conducted in this study employed "exposure profiling" to quantify source emission contributions. This method is based on the isokinetic profiling concept used in conventional (stack) testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique, which uses a mass flux measurement scheme similar to EPA Method 5 for stack testing, does not require an indirect emission rate calculation through the application of a generalized atmospheric dispersion model.

## Air Sampling Equipment

For measurement of particulate emissions from the test road, a vertical network of samplers was positioned 5 m downwind and 10 m upwind from the edge of the road. As shown in Tables 1a and 1b, the equipment deployment scheme made use of three downwind vertical sampling arrays, D1 through D3. Downwind arrays D1 and D3 (as well as upwind array U2) used high-volume (hi-vol) air samplers equipped with cyclone PM-10 inlets and critical orifice flow controllers. Arrays D2 and U1 used hi-vols equipped with Wedging PM-10 inlets and critical orifice flow controllers.

The PM-10 deposits were collected on either Type AH grade glass fiber on QM-A microquartz 8- by 10-in filters. Ten percent of the filters taken to the field were used as blanks.

During the winter tests, the two vertical profiler arrays (D1 and D3) were located about 10 m apart. As such, the profilers can be considered as "collocated" with comparable measurements made.

During the September test, the two profilers were located a considerable distance from each other and thus represent independent measures of road emissions.

Also during the winter tests, the PM-10 samples collected at each height for one profiler array per test were analyzed for lead (Pb), sodium (Na<sup>+</sup>) and chloride (Cl<sup>-</sup>). The PM-10 (and lead measurements) made by the two Wedging reference instruments were used for comparison against data collected by the cyclone samplers. Standard EPA analytical protocols and associated QA/QC procedures were used for this purpose.

## Ancillary Data Collection

In conjunction with the emissions tests, samples of the antiskid material applied to the road (winter testing only) and the dust on the road surface were obtained. These samples were needed to evaluate the performance of existing emission models. The samples collected were analyzed for (a) silt content by dry sieving and (b) percent insoluble matter using ASTM E534, as an indirect indicator of residual salt on the road surface.

Vehicle-related parameters were also obtained using a combination of manual and automated counting techniques. Pneumatic tube axle counters were used to obtain traffic volume data. Because these counters record only the number of passing axles, it was necessary to obtain manual traffic mix information (e.g., number of axles per vehicle) to convert axle counts to the number of vehicle passes. Vehicle mixes were observed visually. In addition, a radar gun was used during selected tests to determine the average speed of vehicles passing the sampler array.

Finally, detailed information was collected by Kansas City Parks and Recreation Department (KCP&R) personnel on the weather and condition of the pavement during the course of each winter storm and on the types and amounts of deicing chemical applied.

## Test Results

During the winter tests, exposure profiling was performed after three storms that occurred on February 15 and 16; February 25; and March 18 and 16; 1993. After the February 15 and 16 storm, three tests were attempted with two of these being complete runs. For the February 25 storm, one complete test was performed. During this particular test, however, the road surface was initially damp and later became wet with snow melt. Therefore, these particular data were not included in the emission factor calculations. (Note that this run

**Table 1a. Sampler Deployment for Winter Tests**

Sampler array ID	No. of instruments	Measurement height(s) (m)	Type of sampler or instrument	Parameter(s) measured
U1	1	2	Hi-vol + Wedding Inlet	PM-10, Pb <sup>a</sup>
U2	2	1.5, 3	Hi-vol + Cyclone	PM-10, Pb <sup>b</sup>
D1, D3	4	1, 3, 5, 7	Hi-vol + Cyclone	PM-10 + Na <sup>+</sup> , Cl <sup>-</sup> , Pb <sup>b</sup> (selected arrays only)
D1	1	4	Wind vane	Wind direction
D2	1	2	Hi-vol + Wedding Inlet	PM-10, Pb <sup>a</sup>
D4	2	1, 5	Warm wire anemometer	Wind velocity

<sup>a</sup> Lead analysis by EPA Method 239.1 (inductively coupled plasma atomic absorption spectroscopy).

<sup>b</sup> Lead analysis by EPA Method 200.9 (graphite furnace atomic absorption spectroscopy).

**Table 1b. Sampler Deployment for September Test**

Sampler array ID	No. of instruments	Measurement height(s) (m)	Type of sampler or instrument	Parameter(s) measured
U2	2	3, 5	Hi-vol + cyclone	PM-10
D1, D3	4	1, 3, 5, 7	Hi-vol + cyclone	PM-10
D2	1	2	Hi-vol + Wedding inlet	PM-10
D3	1	4	Wind vane	Wind direction
D3	2	1, 5	Warm wire anemometer	Wind velocity
D4	1	3	Wind vane/propeller anemometer	Wind velocity and direction

sampled fine salt spray produced by passing vehicles and *not* particulate matter in the traditional sense.) The third test followed the March 18 and 19 storm.

In September 1993, one successful test was performed two days after a major rain storm. During this test, 47th Street was used by heavy vehicle traffic exiting the flood control project located south of the test site. The heavy trucks exiting the project caused a substantial increase in the silt loading measured on the road surface compared to the winter testing. This increase in silt loading was reflected in the measured PM-10 emissions as discussed below.

### Exposure-Profiling Results

The results of the exposure-profiling tests performed on the filter samples collected in the field are summarized in Table 2. These results were obtained by first calculating the blank-corrected PM-10 concentrations at the various sampling locations. The net (i.e., upwind-corrected) PM-10 concentrations were then calculated at each height by subtracting the average of the upwind concentrations determined by Array U2. Using these net concentrations, the net PM-10 exposure was calculated for each sampler location and the exposure profile was integrated. Finally, PM-

10 emission factors were calculated from the data.

As mentioned above, selected filters (including blank filters) from each of the winter tests were submitted for chemical analysis of Pb, Na<sup>+</sup>, and Cl<sup>-</sup> content. The concentration of Pb in the PM-10 samples was determined by two methods. In the first method, filters from the two Wedding samplers (Arrays U1 and D2) were acid extracted and analyzed by inductively coupled plasma spectroscopy (ICP). In the second technique, filters from one profiler array (as well as Array U2) for each test were acid extracted and analyzed by graphite furnace atomic absorption (GFAA). Since none of the filters analyzed by the ICP method were above the instrumental detection limit, only the results of the lead analyses conducted by GFAA were used to calculate compound-specific PM-10 emission factors.

For Na<sup>+</sup> and Cl<sup>-</sup>, filter sets from one downwind profiler array for each test (and Array U2) were submitted for chemical analysis. The purpose of these analyses was to determine the relative contribution of rock salt to the total PM-10 emissions from the roadway. NA<sup>+</sup> was determined using flame atomic absorption and Cl<sup>-</sup> by ion chromatography.

Using the results of the chemical analyses performed, compound-specific PM-10

emission factors were calculated for both Pb and NaCl. The same calculation procedure outlined previously for total PM-10 was used for this purpose. The emission factors obtained in this study for Pb and NaCl are presented in Table 3.

### Results of Ancillary Sampling and Analysis

A sample of rock salt was collected from the KCP&R storage pile. This sample was split and analyzed for silt content and percent insoluble matter. The analytical results obtained for the antiskid material samples collected were: silt = 1.6 wt %; and insolubles = 2.3 wt %.

Road surface sampling was also performed from December 1992 through September 1993. The silt loadings measured in this period varied over about two orders of magnitude (0.02 to 1.4g/m<sup>2</sup>) with the highest silt loading value obtained in September. Except for the two samples collected in January, the insoluble matter found in the silt fell within a fairly narrow range of 91 to 98% (i.e., 2 to 9% water soluble fraction) regardless of time of year.

### Discussion of Results

As shown by the above results, the PM-10 emission factors determined from the wintertime test data are not related to the amount of NaCl applied to the road surface during each storm tested. This is consistent with the fact that NaCl constitutes only a minor portion of the surface silt loading. The NaCl apparently goes into solution and is largely removed from the road surface before it dries. The winter surface silt loading consists largely of insoluble matter *not* derived directly from the chemical deicer (rock salt) but instead from other types of materials. The origin of this loading may be related to pavement wear and "potholing," which could be an indirect result of the deicing chemical used.

A comparison of these results with those of a 1992 Duluth emission study of the effects of antiskid abrasives is also of interest. As can be observed from Table 4, the PM-10 emission factors measured in 1992 for a sand/ salt mixture (90% sand/ 10% rock salt) are substantially higher than those determined after the application of rock salt in the present study, by as much as an order of magnitude. These data would indicate that the application of antiskid abrasives is of far greater concern in the control of PM-10 emissions from paved roads than is the case for chloride deicers.

Finally, a comparison of the measured PM-10 emission factors with those predicted by Eq. (1) from the silt-loading data

**Table 2. Results of PM-10 Emission Factor Calculations<sup>a</sup>**

Run No.	Array No.	Sampler height (m)	Net PM <sub>10</sub> concentration (µg/std m <sup>3</sup> ) <sup>b</sup>	Wind speed (m/s)	Net PM <sub>10</sub> exposure (µg/cm <sup>2</sup> ) <sup>c</sup>	Integrated exposure (m-µg/cm <sup>2</sup> ) <sup>d</sup>	No. of vehicle passes	Measured PM <sub>10</sub> emission factor (g/VKT) <sup>e</sup>
BC-1 (2/17/93)	D1	1	8.66	1.8	16.8	44.5	2245	0.20
		3	2.20	(2.6)	6.18			
		5	0.0	3.0	0.0			
		7	0.0	(3.3)	0.0			
BC-3 (2/19/93)	D1	1	12.11	3.4	61.8	224	3577	0.63
		3	7.13	(3.8)	40.6			
		5	1.04	3.9	6.08			
		7	0.25	(4.1)	1.54			
	D3	1	50.58	3.4	249	606	3552	1.7
		3	9.19	(3.8)	50.5			
		5	3.04	3.9	17.1			
		7	2.13	(4.1)	12.6			
BC-5 (3/20/93)	D1	1	15.41	1.1	27.7	135	3617	0.37
		3	7.32	(1.7)	20.3			
		5	4.06	1.9	12.6			
		7	1.88	(2.1)	6.44			
	D3	1	13.33	1.1	24.0	118	3639	0.32
		3	6.30	(1.7)	17.5			
		5	3.92	1.9	12.2			
		7	1.61	(2.1)	5.53			
BC-12 (9/16/93)	D1	1	241.9	1.0	118	381	969	3.9
		3	85.18	(1.1)	45.5			
		5	40.08	1.2	23.4			
		7	20.15	(1.2)	11.8			
	D3	1	177.1	1.1	97.0	497	1016	4.9
		3	117.2	(1.3)	75.9			
		5	57.07	1.3	37.0			
		7	36.51	(1.4)	25.5			
		(9)	(16.00)	(1.5)	12.0			

<sup>a</sup> () indicates inter/extrapolated value.<sup>b</sup> Net concentration calculated as difference between average upwind concentration (Array U2) and downwind concentration at each sampler height.<sup>c</sup> Rounded to three significant figures.<sup>d</sup> Integration scheme assumes constant exposure from 0 to 1 m height with Simpson's approximation used for integration between 1 m and effective plume height (H).<sup>e</sup> Rounded to two significant figures.**Table 3. Results of Compound-Specific PM-10 Emission Factor Calculations (Winter Tests)<sup>a</sup>**

Run No.	Array No.	No. of vehicles passes	Lead emission factor (g/VKT)	NaCl emission factor (g/VKT)
BC-1 (2/17/93)	D1	2,245	Nil	0.039
BC-3 (2/19/93)	D3	3,552	7.05 (10) <sup>-5</sup>	0.021
BC-5 (3/20/93)	D1	3,617	4.3 (10) <sup>-4</sup>	0.014

<sup>a</sup> Includes only Pb or NaCl found in particles < 10 µm in aerodynamic diameter. Rounded to two significant figures.

**Table 4.** Emission Factors Developed During 1992 Duluth Testing Program<sup>a</sup>

Run No.	Array No.	No. of vehicle passes	PM-10 emission factor (g/VKT)
AY-3	D-1	1,175	3.91
	D-4	983	10.6
AY-4	D-1	220	1.44
AY-5	D-4	650	2.29

<sup>a</sup> From Kinsey (1993).

**Table 5.** Ratio of Predicted to Measured PM-10 Emissions

1993 date	Run No.	Array No.	Measured silt loading (g/m <sup>2</sup> )	Measured PM-10 emission factor (g/VKT)	Predicted PM-10 emission factor (g/VKT)	Ratio of predicted to measured emissions
2/17	BC-1	D1	0.061 <sup>a</sup>	0.20	0.26	1.3
3/20	BC-5	D1	0.55	0.37	1.08	2.9
		D3		0.32		3.4
9/16	BC-12	D1	1.44	3.9	3.7	0.95
		D3		4.9		0.76

<sup>a</sup> Determined on 2/18/93.

yields some interesting results. As shown in Table 5, the measured emission factors agree well with the predicted values, taking into account the confidence interval associated with Eq. (1). The 16 confidence interval for Eq. (1), which is a good measure of its average uncertainty of prediction, is a factor of 4.2.

## Study Conclusions

The winter PM-10 emission factors determined in this study of the effects of a chemical deicer (NaCl) were generally low, ranging from 0.2 to 1.7 g/VKT. In contrast, the winter emission factors measured in the earlier Duluth study of the effects of antiskid abrasives were about an order of magnitude higher. Thus the use of antiskid abrasives is much more significant than the chemical deicer, in terms of PM-10 emission impact.

Rather than increasing the surface silt loading, NaCl aids in cleaning the road by forming slush which is either picked up on

vehicle underbodies, cast aside, or removed as runoff. Little NaCl is left in the residual silt loading once the road surface has dried. Insoluble materials from other sources (possibly including pavement deterioration enhanced by the NaCl) drive the PM-10 emission rate.

The compound-specific PM-10 emission factors for Pb and NaCl, as determined in the winter testing, ranged from  $7.5 (10)^{-5}$  to  $4.5 (10)^{-4}$  g/VKT and 0.014 to 0.039 g/VKT, respectively. Due to the low magnitude of these emission factors, the contributions of both analytes to the total PM-10 emissions from the road can be considered negligible.

The PM-10 emission factor equation (in the 5th edition of report AP-42) is a reliable tool for predicting emission rates from measured winter silt loading. The uncertainty in the predictions is well within the previously determined reliability of the equation.

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*The complete report, entitled "Characterization of PM-10 Emissions from Antiskid Materials Applied to Ice- and Snow-Covered Roadways—Phase II," (Order No. PB95-260402; Cost: \$27.00, subject to change) will be available only from:*

*National Technical Information Service*

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